Designing Worked Examples in Statics to Promote an Expert Stance: Working THRU vs. Working OUT

Robert Calfee and Thomas Stahovich, University of California Riverside

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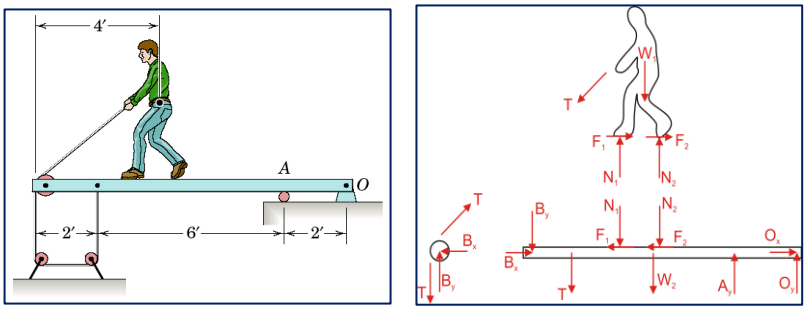
Introduction: Context of the Project. A major barrier to completion of the undergraduate Engineering degree is completion of two courses in Mechanical Engineering, *Statics* and *Dynamics*. In Statics, one requirement is learning to solve *freebody diagram* problems. In this task, the student is presented a concrete situation like that in Figure EX1, showing one or more objects along with the forces acting on the system. The first job is to construct an abstract drawing of the objects and forces, which then allows writing equations for analysis of the forces at work in the system. Constructing the freebody diagram requires a perceptual analysis of the original problem, which can pose a variety of challenges, such as deciding which elements to combine and which to separate, and how to represent various forces. Most students have previously encountered similar tasks in high school physics, but these problems were generally simple sketches, such as a set of blocks and cables, requiring less perceptual work than the situation in Figure EX1.



(a) (b)

Figure EX1. Illustration of a statics problem in Mechanical Engineering (a), and (b) a freebody diagram constructed to represent the problem (b). Part (a) from Meriam & Kraige, 2007.

Students are taught to solve freebody problems through lectures and textbooks, the former including one or more worked examples by the instructor, and the latter providing both worked examples and homework assignments (cf. Atkinson, Derry, Renkl, & Wortham, 2000, for a comprehensive review of the concept of *worked examples*). These learning resources vary in the level of detail about solution steps, and seldom allow dynamic interactions with students, although discussion sections may include such activities.

This study explores data from an investigation of individual differences among students in the early stages of acquiring the freebody concept. *Newton's Pen* (Lee, de Silva, Peterson, Calfee, & Stahovich, 2008) reported findings from a pilot study in which Engineering freshmen completed a computer-based pen (CBP) tutorial designed to assist them in acquiring the free body diagram concept. The students showed substantial improvements in performance over the course of an hour-long session;

few students could solve the pretest problem at the outset, while everyone handled the same problem efficiently and effectively following the tutorial.

The paper presents a secondary analysis of *Newton's Pen* exploring individual differences in how students approached the problem. Some students *worked out* the problem, proceeding hastily and making numerous mistakes in an apparent effort to complete the assignment quickly and by any means possible. Other students *worked through* the problems, taking time to study instructions, keeping multiple pages in view during the task, reflecting on their mistakes, and in general displaying characteristics typical of expert performance. In this paper we propose the concept of an *expert stance* to describe the second group, and then consider ways in which a CBP platform might promote this stance during learning of the freebody task.

The Computer-based Pen Platform. CBPs such as those developed by the Anoto Group provide a novel platform for the writer, where "writing" may encompass activities ranging from prose to scribbles, from outlines to semantic webs, sketches, cartoons, and schematic drawings -- virtually anything that can be captured with pen and paper. Advanced CBP platforms such as Livescribe's Pulse (Figure 2LS) provide a variety of supportive functions, including storage of audio and graphic material to support note-taking and pencasting activities, and a docking capacity that allows exchange of information between the pen and a digital computer.

Figure 2LS. The Livescribe Pulse, a Computer-based Pen Platform.

CBPs have both advantages and limitations compared with platforms such as pencil-paper, keyboard-mouse, tablet PCs and I-PADs, and PDAs. The pros and cons hinge on factors such as cost, flexibility, convenience, and power, among other considerations. Oviatt (in press; also Oviatt & Cohen, 2010, Oviatt, 2006, and van Schaack, 2009) has reviewed these issues from conceptual and empirical perspectives, and has conducted several studies with high school students engaged in solving science and mathematics problems. This research revealed that digital pen and paper interfaces entail affordances that stimulate higher rates of nonlinguistic communication (e.g., diagramming, symbols, and numbers), ideational fluency, problem solving, and retention of domain content, compared with other graphical interfaces such as PCs and pencil-paper platforms. They also appear to lower cognitive load, provide more effective support for low-performing students, and reduce expansion of the performance gaps among student groups. As an example of the functional advantages of CBPs, students can spread out an array of pages while working on a problem, allowing continuous spatial referencing (Jang, Schunn, & Nokes, 2011). A full treatment of these issues falls outside the purpose of this paper, which will focus on the role of *worked examples* during learning (Atkinson, et al., 2000), and the educational potential of CBPs in this setting.

Over the past several years, we have explored the application of the CBP platform for the development of tutorial situations to enhance performance on and understanding of homework exercises assigned to beginning engineering students in the statics course. Mechanics courses serve as a significant gateway in the path toward completion of the Engineering major. Homework assignments are important both in their own right and in preparing students for examinations. Engineering textbooks contain substantial numbers of homework exercises, along with worked examples. Following the release of a new edition for any of the standard textbooks, however, solutions to the homework exercise sets quickly

become available on the internet, which students can reproduce in homework assignments with minimal effort, with little or no reflection, and – in all likelihood – with limited impact on learning and understanding.

Novice efforts to work through a statics problem without assistance can be difficult and frustrating, which explains why students turn to short cuts. We have employed the CBP platform to support students during completion of freebody diagrams in several experiments, some aimed toward the validation of assessment techniques, and others in which tutorial techniques were the focus. This report uses data from sixteen participants in a pilot project, *Newton's Pen*, where the CBP platform provided tutorial support (Lee, de Silva, Peterson, Calfee, & Stahovich, 2007). The research design employed a within–subjects design in which participants completed a pretest (the "Ring" problem, Figure 3RING) followed by a worked-example tutorial in which they completed a freebody diagram problem while a worked example was available for reference. Two problems were developed for the tutorial and transfer-test phases, the Inclined Plane (IP) and Friction (FR) problems. For half the participants, the IP problem served for the tutorial and the FR problem for the transfer test; for the other participants, the order was reversed. Participants first attempted the Ring Pretest, which presented a considerable challenge for most of them. Analysis of performance on the assessment series (pretest, posttest, re-pretest) reported in Lee, et al. (2007) showed that all participants subsequently attained high levels of success and expressed satisfaction following the Tutorial.

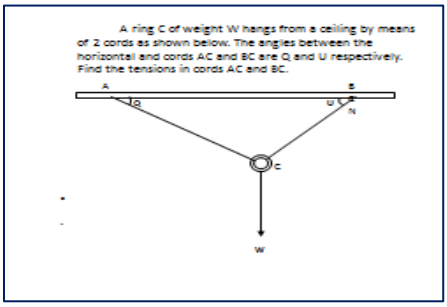


Figure 3RING. The "Ring," which served as a pretest for *Newton's Pen.*

This paper explores performance during the Tutorial, a "worked example" scenario, during which a scaffolded support system was available to participants using the CBP platform for implementation. The Tutorial began with a segment on using the pen to "compose" the features required during analysis of a freebody diagram: drawing force arrows and angles, labeling various elements, and so on. After this segment, participants were presented the freebody problem and a model of a worked example (Figure 4WE illustrates the tutorial system for the Ring problem). Following the worked example, students were presented a page with a box where the student was to sketch the freebody diagram, and a second page for writing the force equations. This paper focuses on analyses of behavior during the freebody sketches; performance on the equations will not be covered here.

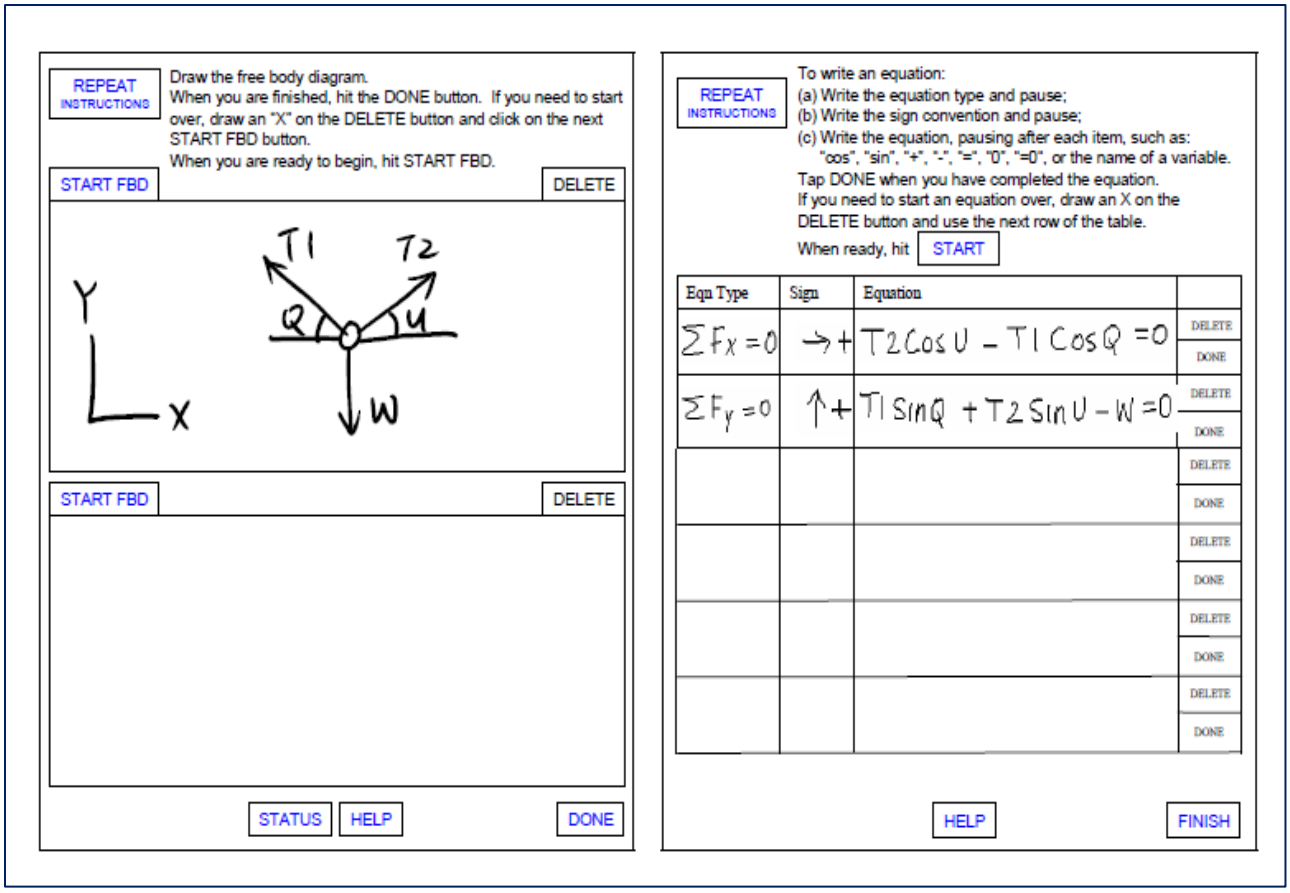


Figure 4WE. Newton's Pen Tutorial Layout for Ring Pretest.

The tutorial guided students through several activities. They first constructed an X-Y coordinate system as a reference, next drew the freebody, and then added the force vectors. Following each stroke, the CBP responded aurally with feedback about the correctness of the stroke, and offered guidance about how the participant should next proceed. If the participant was unclear about the feedback, a Help icon was also available with three levels of assistance: Level 1offered general guidance, Level 2 a more focused hint, and Level 3 gave the exact answer. The CBP prototype used for the pilot study had limitations; in particular, feedback to responses was rather slow. Although participants were advised to wait for feedback, many were impatient and moved ahead before receiving feedback to a particular response, which led to complications during the first part of the Tutorial. Note that the Worked Example was available for review throughout the reproduction process, a feature of the tutorial that was possible with the CBP platform, because unlike a laptop computer, the worksheets could be spread out on the table. Notice also that a participant could complete the Tutorial by simply copying the worked-example model. Finally, a participant could jump to Level 3 of the Help icon to obtain detailed help, allowing completion of the transfer tasks without doing any work.

In setting the stage for the following analyses, we should remark that every participant appeared to attempt more than the "copy" defaults mentioned above. Participants were volunteers from a beginning Physics class, had just completed an introductory lecture on freebody diagrams, and had received homework assignments that were due the following week. It is reasonable to assume that they were strongly motivated to learn something during the tutorial session. All students seemed engaged in doing

more than simply reproducing the worked-example model, and in general seemed to be trying to understand the freebody process. In reviewing tutorials during test scoring, however, we noticed substantial individual differences among participants in how they approached the task. Some individuals tapped the Help icon much more than others, appearing in some instances to be relying on the third and most specific Help level in order to reproduce the worked example with limited effort. Other individuals were remarkable because of the extended time they spent studying the worked-example before turning the page. They also tended to spread out the pages rather than placing them into a stack, a behavior typical of the first group.

The *Newton's* Pen data set provides a rich context for generating hypotheses about student strategies during a WE task. The WE literature has explored various techniques for optimizing the value of an example; e.g., by eliminating irrelevant distracters that might increase cognitive load and impair performance (cf. Rossow, 2005; Atkinson, Renkl, & Merrill, 2003, for comprehensive reviews of this literature). Newton's Pen, because of the fine-grained nature of the data, allows detailed exploration of contrasts between what we have labeled "worked-out" versus "worked through" responses. Atkinson, et al. (2003) used "worked out" to describe a prompt paradigm that they employed in place of the "figure it out yourself" strategy employed in many WE investigations. Meier, Reinhard, Carter, & Brooks (2008) embedded computer-supported "elaborated worked-example modeling" in scenarios for students during a forensic science class. They found that these augmentations enhanced learning for novices.

In a major conceptual move, Meier, et al. (2008) also introduced the *novice-expert contrast* as background for conceptualizing the approaches used by more or less successful students during WE exercises. Numerous investigations have revealed distinctions between novices and experts, yielding a profile of expert performance characterized by the features shown in Table 1ExpNov. A consistent feature of expert problem-solving, emphasized by boldface in the table, is the tendency to allocate a significant amount of time to examination of the situation. Before beginning work on a problem, experts tend to study the problem very carefully. They also show give evidence of self-reflection, of monitoring and reviewing their performance, especially when they make mistakes.

Table 1ExpNov. Characteristics of Expert Performance (After Chi & Glaser, 1988)

- Excel in a specific domain
- Process information in large units
- Performance is fast and smooth
- Hold more information in memory
- Represent problems at a deeper level
- **Spend more time analyzing the problem**
- **Are better monitors of their performance**

The novice-expert distinction seems to us to have significant parallels to the work-out vs. work-through contrast that we have adopted to describe variations in the Tutorial activities of *Newton's Pen* participants. A qualitative analysis of the data set generated several indicators that we plan to use in further investigations of other data sets now under analysis. The notion of exploring individual differences in WE performance during completion of a tutorial package appears to be innovative in its own right; Atkinson, Derry, Renkl, and Wortham (2000) mention "individual differences" in their review of WE papers, but their emphasis is on self-explanation findings rather than individual differences.

Table EXCL displays the Excel template used to compare selected performance features during the Tutorial. The task was divided into several segments, for each of which beginning and ending times are noted. Comments were written for each segment based on information from the videos and the sketch performance recorded by the Pen. The Table provides brief samples from two cases, the first typical of the WORK-OUT profile and the second of the WORK-THRU profile.

Table 2EXCL. Spreadsheet template for qualitative analysis of informant profiles during Worked-Example Tutorial Exercise.

	SUBJECT N2 WORK-OUT Very literal, relied on copying with help.		SUBJECT N4	WORK-THRU Knows the task but continuously checks the territory
PHASE	TIME	Comments	TIME	Comments
Intro to FLY	0:00		0:00	
End Intro	6:00	Difficulty learning to use Pen.	:30	Very workmanlike -- moved quickly when sure
Strt Pre	6:40	"I'm stupid as they come; don't know this stuff"	:35	Very busy on task; need to study detail
Strt Tutorial	7:40	Problems copying	3:40	Told to copy
End Pract	9:55		5:45	Asked for clarification
Strt FBDraw	10:00	"Just copy?" -- yes	6:30	"Just copy"
Strt FB Cood	10:40	"Help" didn't help	6:45	Very smooth
Strt FB	12:00	slow to draw 4 lines; persisted	6:50	
Strt Force	12:40	Relied on help to 3rd level	7:15	
End FBDraw	15:50		8:30	Smooth
Strt Eqn	15:55	"Look at FB while doing Eq"	8:40	
Strt Eqn 1	16:45	"Term by term" finally; no attention to diagram	9:40	Asked for clarification
Strt Eqn 2	19:00	Speeded up when relied only on copying.	11:10	Asked for clarification
End Sessn	20:10		12:25	

Response time provided a revealing indicator when segmented as shown in the spreadsheet. Figure 5TIMES shows the proportion of total time taken by two informants in each of the freebody-sketch segments, normalized by total sketch time. The first time metric was the length of the initial examination. Some participants took 30 seconds or less to study the worked-example model before beginning to draw/copy the model. Others took three minutes or more to complete the examination. Another set of quantitative metrics were the times for completing various segments of the freebody diagram. As indicated in Figure 5TIMES, Work-THRU participants tended to proceed quite smoothly in sketching a segment once they started to draw, while Work-OUT learners were more likely to proceed in a jerky, start-stop fashion, which meant that they took longer to complete the sketch elements.

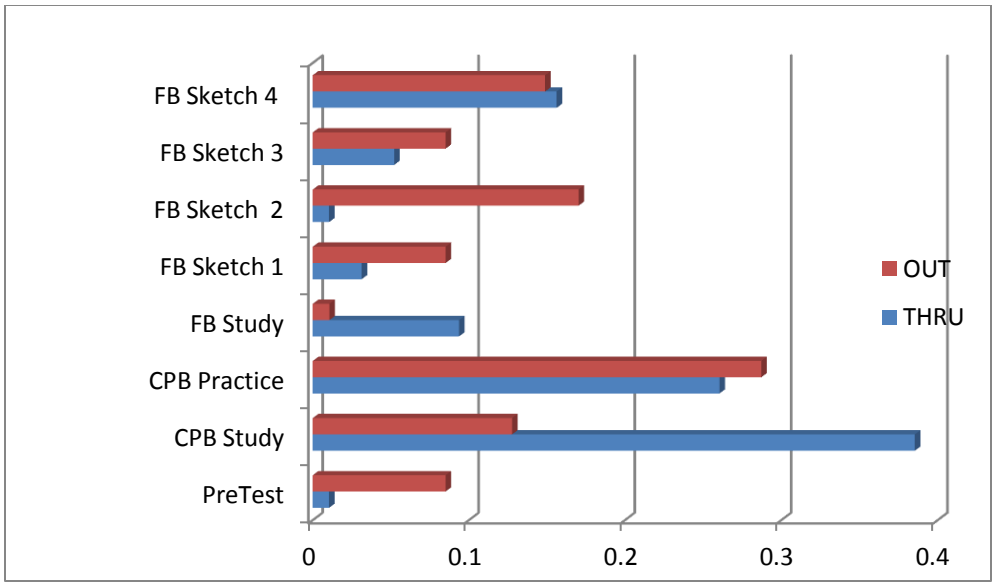


Figure 5TIMES. Proportion of freebody sketch time taken by each of two informants, normalized on total sketch time.

Participants were encouraged to think aloud during all of the tasks. Only a few complied with this request, however, and so we have limited evidence about what they might have been thinking. In similar fashion, most participants seldom asked questions of the examiner, perhaps because of the implied assumption that the Pen was supposed to do the talking. On the other hand, several participants offered spontaneous remarks during the task, samples of which are provided in Table 2EXCL. Work-THRU respondents were more likely to comment on the task, while Work-OUT learners typically offered personal reactions to the situation. Interestingly, the informants labeled as THRU and OUT did not differ greatly in the total amount of time they spent working on the problems, and virtually everyone succeeded on the Post and Post-Post problems. The observed differences tended to be in the way that work time was distributed, and in the number of mistakes along the way.

Another contrast of potential significance appears in responses to errors and feedback. Some participants quickly tapped the Help icon once they discovered how it worked. They often repeated a previous response following a mistake, generally to little avail. These participants tended to react in scattershot fashion when confronted with negative feedback; they seldom paused to reflect on various explanations and options available to them, but rather continued to draw strokes in a haphazard manner.

Table 3THRU-OUT summarizes the contrasts drawn above. The data set is small, and serves descriptive rather than inferential purposes. Nonetheless, the patterns are sufficiently consistent that we think that they warrant attention, and that the novice-expert distinction may have conceptual and practical value in thinking about the THRU-OUT contrast.

Table 3THRU-OUT. Summary of Contrasts between Work-OUT and Work-Thru profile	
Work THRU	**Work OUT**
• Spends significant time studying instructions and reading the problem • Refers to instructions and previous work frequently during the task • Uses hints and help selectively • Studies mistakes carefully; seldom repeats	• Skims quickly through instruction • Goes to work quickly on a problem • Uses hints/help frequently to move past barriers • Learns little from mistakes, which tend to be repeated

We propose that the Work-THRU profile may signal progress by a novice student toward development of expertise, a situation that we have labeled as the adoption of an *expert stance*. Our hypothesis is that certain performance characteristics play a critical role in making progress toward expertise, including the two bold-faced elements highlighted at the bottom of Table 1ExpNov. These characteristics call to mind metacognitive activities in which a learner stands apart from ongoing performance, often "thinking aloud." An important correlate of metacognitive activities is the presence of reflective and self-regulatory actions. As Oviatt (in press, Chapter 11) notes, individuals differ in their tendencies toward a reflective versus an impulsive style, but these tendencies also depend on the activity context. For example, multi-tasking environments seem to foster impulsive reactions, while tasks that call for written activities lead to more reflective responses. Oviatt does not report on studies of instruction explicitly designed to foster a reflective, metacognitive posture, but offers a number of suggestions that seem useful starting points for such endeavors.

Pathways to expertise. An idea of potential importance springing from these analyses is the notion that employing the Work-THRU approach may support the movement from novice to expert. From this reasoning, a significant instructional question centers on the design of activities that might promote a Work-Through strategy, that could provide students with feedback not only on content-relevant aspects of performance, but also on performance characteristics that conform to or differ from the Work-THRU profile. The CBP platform offers a variety of opportunities for exploring this hypothesis, and for designing tutorial programs that reinforce significant features of the Work-THRU profile.

An important next move in our work is accordingly an attempt to formulate and evaluate conditions that foster a "worked through" approach to worked-example opportunities. For a variety of reasons, copying a model (the ultimate OUT approach) has considerable appeal to students; it is easy, fast, and requires little effort, mental or otherwise. An even simpler approach is to glance at the model and move on. While this approach offers an easy approach to homework assignments, it probably provides limited support for transfer to situations with more difficult problems, or in more closely monitored settings such as in-class examinations.

The **expert stance** emerges in learners who, for whatever reason, approach a domain with a reflective, metacognitive attitude, which on the surface may seem slow and tedious, bringing to mind the tale of the "hare and tortoise," but which may be critical for moving toward expertise. The prevailing tendency seems to be for students to try to emulate fluent expert performance (the teacher, for example), but such efforts may turn out to be disadvantageous for novice learning. The attainment of speeded

behavior is likely to require an apprenticeship during which the essential building blocks for dealing with a domain are explored gradually and with attention to mistakes and dead ends (one is reminded of the tutorials in *The king's speech*). Chi (2006/46, Table 2.1) presents levels of a proficiency scale (Novice, Initiate, Apprentice, Journeyman, Expert, Master) that suggest a series of qualitatively distinctive stages in the progression from novice to expert and beyond, an idea that would seem to warrant further thought and empirical study.

Instruction that promotes an expert stance may entail the application of *adaptive expertise* (Hatano & Imagaki, 1986), in which accomplished performance is slowed down and analyzed, as though the situation is being viewed simultaneously through both expert and novice lenses. Adaptive expertise may be a critical element undergirding the expert's capacity to explain the problem-solving process in a particular situation (Hmelo-Silver & Pfeffer, 2003). The tutorial principles employed in the design of *Newton's Pen* were relatively simple: provide immediate feedback along with graduated levels of assistance. Augmentations to promote an expert stance would include attention to both time and space: "(1) Take time to study the problem, to think about what you are doing and why, and (2) be sure to keep all of the information that you need in view, and to regularly survey the situation." These are relatively simple principles, but implementing them in conjunction with feedback and graduated help will require further design work, both conceptual and empirical. The extensive literature on cognitive load theory, which has served as the basis for much of the empirical information on worked examples, also needs to be added to this mix (cf. Sweller, Ayres, & Kalyuga, 2011; Plass, Moreno, & Brunken, 2010, for recent reviews). *Cognitive load theory* proposes that task performance, particularly for individuals in the early stages of learning a complex task, can become chaotic if contextual circumstances overload the mental resources available for the task. The learner then spends so much energy managing resources that little remains to handle the substance of the problem. Oviatt (in press) emphasizes the advantages of digital pens for reducing extraneous interface load while increasing germane load in tasks such as constructing diagrams while working on STEM problems.

In summary, our thinking about the development of expertise has led us to consider a multiphase pathway toward the acquisition of expertise:

- Adopting a metacognitive stance, with more attention to analysis of the problem, reflection on mistakes, and ongoing review of performance, including "looking at all of the pieces."
- Seeking assistance in more fully understanding how to approach a domain; asking for help; thinking about the implications of various courses of action.
- Constructing a mental model of the domain, probably in segments or chunks (Simon, 1996), interactively, and shaped by experiences with a variety of different problems in the domain.
- Repeated practice and feedback, refinement and automatization of templates, for both structures and processes.
- Leading eventually to speed and internalization of learning.

Expertise, in this formulation, is not a gradual progression across all facets of accomplishment, but proceeds through advances in selected facets, with reflection and self-monitoring playing a critical role in the early stages, and during later stages when new situations require rethinking the problem context.

Concluding Thoughts

Our studies of CBP-based tutorials were initially motivated by questions about the effectiveness of different platforms. Several features of smart pens appear advantageous when compared with alternatives such as tablet PCs and IPads. Paper-pencil technology is commonplace from the early ages onward, which may be why learners tend to perform better with smart pens on a variety of cognitive metrics (Oviatt & Cohen, 2010; Stahovich et al., ASEE, 2011). The smart-pen platform allows students to display multiple sheets of paper for ongoing reference during learning. In *Newton's Pen,* learners had to manage a collection of different pages: instructions for using the Pen, information about the problem and the tutorial model, their own work on the FBD sketch, and so on. Many students made limited use of these resources; they placed successive sheets of paper on top of each other or otherwise disregarded them. One notable characteristic of Work-THRU learners was their ongoing reference to these materials, suggesting that a pen-paper environment which may have been an important feature of their problem-solving strategy (Jang, Schunn, & Nokes, 2011). We are not suggesting that any given platform be given priority over others, but rather see advantages to instructional design that builds upon a seamless collection of devices, including smart pens, but also incorporating personal and tablet PCs, white boards, and so on.

A second line of reasoning from the current study centers on the tutorial design. Virtually every student showed considerable progress during the hour-long tutorial. Some reasons for the change are the usual suspects: individualized practice with immediate feedback, opportunities for constructivist engagement with the task, and the innovative platform. They were also motivated by the upcoming homework assignment. Other reasons may spring from new twists on old favorites: the availability of dynamic worked examples, and ready access to hints and helps.

The emergence of the *expert stance* during the performance of some learners raises several other questions about effective and efficient instructional design. Some issues are rather general, others specific to the freebody diagram situation. For example, it may make sense to incorporate procedures that promote reflective thought (e.g., "you should take time to study the instructions and the problem") and to discourage "quicky" responses, as when a student moves rapidly from one page to another. Individual tutorials could also offer guidance about strategies for responding to errors of various types. The difficulty of sketching a freebody diagram depends on the complexity of the problem, which may not be immediately obvious to the novice. For example, the two problems in Figure 6JAWS may appear similar on the surface, but they call for quite different solution strategies. Examination of learners' freebody sketches can quickly reveal whether a learner perceives these conceptual differences, information that can then serve for tutorial guidance.

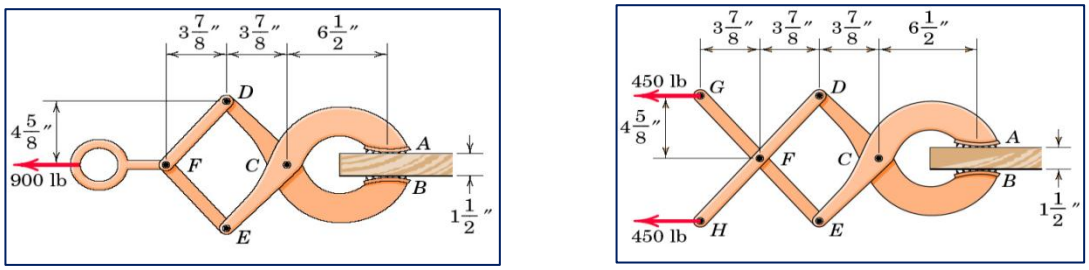


Figure 6JAWS: Devices with superficial similarity but conceptual differences. On the left, DF and EF are two-force members. On the right, there are no two-force members. (Figures from Meriam & Kraige, 2007].)

Our final thoughts revolve around implications for promoting the adoption of an expert stance in this setting. Developmental considerations are seldom mentioned in the expert-novice literature, but the attainment of expertise in a well-defined domain seldom emerges prior to secondary education, and more typically after an individual begins to pursue a career or a craft. The decision to pursue a degree/career in engineering or other professions and crafts often entails a commitment to the attainment of expertise, which means moving through a series of stages from apprentice to master (Chi, 2006). Early in this path, students may not be fully aware of the changed situation, but they become gradually aware that schooling is "serious," with the attendant need to adopt new attitudes and habits, which we suggest should include adopting an *expert stance* toward learning. Above we discussed some practical aspects of such a stance: taking time to reflect on problems, learning from mistakes, and so on. From a broader perspective, the expert stance can be seen as one element in a package designed to promote success by all students who decide to pursue careers in engineering and other high-stress, low-retention fields. Developing such a package may appear to be a daunting task, but we suggest that it is more approachable when decomposed into "bite-size" segments, for which *Newton's Pen* may serve as a workable model.

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